DOCUMENT RESUME

ED 252 179 IR 011 438

AUTHOR Brophy, Jere; Hannon, Patrick
TITLE The Future of Microcomputers in the Classroom. Occasional Paper No. 76.
INSTITUTION Michigan State Univ., East Lansing. Inst. for Research on Teaching.
SPONS AGENCY National Inst. of Education (ED), Washington, DC.
PUB DATE Sep 84
CONTRACT 400-81-0014
NOTE 36p.
PUB TYPE Information Analyses (070) -- Viewpoints (120)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Computer Assisted Instruction; *Computer Oriented Programs; Costs; *Courseware; Instructional Innovation; Literature Reviews; Program Effectiveness; *Programing; *Teaching Methods
IDENTIFIERS *Computer Uses in Education; Instructional Effectiveness

ABSTRACT

Present and potential classroom applications of microcomputers are examined in this literature review, which was conducted to identify both unjustified and well-founded claims about the advantages offered by the introduction of computers into classroom instruction. Conclusions presented indicate that: (1) such applications are being oversold by enthusiasts who make unjustified claims about the presumed need for and benefits of introducing computers to the classroom (in general) and of teaching students to program computers (in particular), and who underestimate the costs involved (in time, trouble, and money); (2) there nevertheless do appear to be applications (centering around the "three R" functions of recursions, revision, and rapid hypothesis testing) that could allow teachers to expand or improve instruction by doing things they cannot do now; and (3) the realization of most of these applications awaits the development of software that is commonly available at an affordable cost, pedagogically sound, integrated with the rest of the curriculum in the topic area, and designed for use by the teacher working with the class rather than by the student working individually. Twenty references are listed. (Author/LMM)

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ED252179

Occasional Paper No. 76

THE FUTURE OF MICROCOMPUTERS IN THE CLASSROOM

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Published By

The Institute for Research on Teaching
252 Erickson Hall
Michigan State University
East Lansing, Michigan 48824-1034

September 1984

This work is sponsored in part by the Institute for Research on Teaching, College of Education, Michigan State University. The Institute for Research on Teaching is funded primarily by the Program for Teaching and Instruction of the National Institute of Education, United States Department of Education. The opinions expressed in this publication do not necessarily reflect the position, policy, or endorsement of the National Institute of Education. (Contract No. 400-81-0014)

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Abstract

This paper examines present and potential classroom applications of microcomputers. The authors conclude that (1) such applications are being oversold by enthusiasts who make unjustified claims about the presumed need for and benefits of introducing computers to the classroom (in general) and of teaching students to program computers (in particular) and who underestimate the costs involved (in time, trouble, and money); (2) there nevertheless do appear to be applications (centering around the "three R" functions of recursions, revision, and rapid hypothesis testing) that could allow teachers to expand or improve instruction by doing things they cannot do now; and (3) the realization of most of these applications awaits the development of software that is commonly available at an affordable cost, pedagogically sound, integrated with the rest of the curriculum in the topic area, and designed for use by the teacher working with the class rather than by the student working individually.

THE FUTURE OF MICROCOMPUTERS IN THE CLASSROOM[1]

Jere Brophy and Patrick Hannon[2]

Recently, interest in and availability of microcomputers has rapidly increased in the United States. Small businesses are installing them, families are buying them for home use, and schools are using them both for record keeping and classroom instruction. The major manufacturers are competing as hardware suppliers, and both they and a great many smaller companies are producing accompanying software. Most of this software is targeted for commercial applications or (non-educational) video games, but many companies have targeted at least part of their efforts toward educational applications for home and school use. Each week seems to bring forth new books, special issues of journals, and consumer magazines announcing the coming computer revolution in education and offering advice on computer purchase and use in schools.

Enthusiasm abounds in most of these publications. Typically, the authors assume that microcomputers will revolutionize life at home, at school, and in the work place; that education in the future will be largely computerized; and that any educated person will have to know how to program and use microcomputers. In the educational sphere, computers are portrayed as capable not only of accomplishing traditional educational activities such as drill and

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[1]An earlier version of this paper was one of four presentations made by members of the BACOMET (Basic Components of Mathematics Education for Teachers) group to a conference on microcomputers in the classroom held in Oslo, Norway, in May 1984. This paper will appear soon in the Journal of Mathematical Behavior (in press) under the same title. The authors wish to thank the BACOMET group and Zane Berge for their critical comments and June Smith for her assistance in manuscript preparation.

[2]Jere Brophy is IRT co-director and coordinator of the Classroom Strategy Research Project. Patrick Hannon is a research intern with the same project.

practice more effectively than is possible with traditional methods, but also as creating a qualitatively new and better form of education that is more exciting, more rewarding, and more successful in developing higher level thinking and reasoning skills than what even the best of contemporary classrooms have to offer.

Lipson and Fisher (1983), for example, argue that financial restrictions and other practical factors cause contemporary schooling to concentrate too much on declarative factual knowledge (knowing *what*) and not enough on experiential procedural knowledge (knowing *how*). They conclude that abstract, verbal exposition of certain topics will become obsolete as software is developed to allow concrete, visual instruction in those topics, especially instruction that incorporates videodisc technology capable of illustrating movement of three dimensional objects through space and time. Similarly, they predict that schooling will begin to offer a better balance between declarative and procedural knowledge when it incorporates more computerized simulation activities in which students are confronted with realistic problem-solving situations and allowed to explore the consequences of various response strategies.

Papert (1980), whose book, *Mindstorms: Children, Computers, and Powerful Ideas*, has been a major source of inspiration to educators with interests in computer applications, has been particularly eloquent in arguing that computers have the potential to truly revolutionize education, if used properly. He acknowledges that computers can be used for such purposes as drill and practice in basic skills or instruction in BASIC or other programming languages, but he sees these as relatively minor changes that do not take full advantage of the computer's potential. He argues that computers should be

used to expand students' minds by putting them in touch with what he calls "powerful ideas":

> One might say the computer *is being used to program* the child. In my vision, *the child programs the computer* and, in doing so, both acquires a sense of mastery over a piece of the most modern and powerful technology and establishes an intimate contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model building. (Papert, 1980, p. 5)

The exciting prospects generated by such predictions, within the general atmosphere of talk about "the computer revolution," have created strong pressures on schools to purchase and use computers for classroom instruction. Headlines such as "Schools criticized for slow progress in adapting to computers" are commonplace, and the authors of the accompanying articles often take it for granted that computerization of education is both feasible and desirable. Computers are commonly touted with the same unbounded, unfounded enthusiasm as was directed toward such previous fads as educational television, programmed instruction, and open-space architecture. But what is the reality beneath the hype? We address this question here by (1) reviewing information about current trends in classroom use of computers, (2) identifying claims that we believe to be unjustified, and then (3) identifying what appear to be well-founded claims about present or potential advantages offered by the introduction of computers into classroom instruction.

Current Trends in Classroom Computer Use

Surveys of school administrators and teachers concerning classroom computer use quickly become obsolete under the current conditions of rapid proliferation of computer and software availability. Still, even the most recent surveys make it clear that the advantages computers offer to teachers are perceived as limited, and few of the visions of computer enthusiasts have been fulfilled. For example, in an article entitled "Microcomputers: Dreams and

realities," Becker (1982) notes that most programs actually in use in the schools are merely computerized workbooks providing the same old drill and practice without taking advantage of the computer's capacities for record keeping, diagnosis, and provision of corrective tutorial instruction. He expresses doubt that the benefits derived from these programs justify their costs and predicts continued constrast between dreams and realities until producers of educational materials for computers begin to confront some basic problems.

The primary problem is that computer programs are designed to be used by individual students, whereas classroom instruction is group-based. Programs providing demonstrations or simulation activities designed to be used as part of group-based instruction (most likely via videodisc technology that would allow the demonstration or simulation material to be shown to the whole class on large monitors) probably would enjoy popularity with teachers. However, few such programs are available as yet, and most designers of educational software still think of the student, rather than the teacher, as the user.

Just because something can be done by computer does not mean that it should be. Many of the present and projected computer applications in the classroom involve nothing more than doing traditional things by computer instead of other ways, usually with little or no gain and often with considerable costs in time, trouble, or effectiveness.

Teachers who are willing to use the presently available programs intended for use by individual students face financial constraints that limit the availability of computers in any given classroom to just one or only a few (with the exception of courses in computer use and applications). This introduces serious planning, organizational, and management problems that program designers have not seriously addressed. Development of activities

intended for pairs or groups of students working with a single computer would help in this area, but again, few such programs are available. Thus, the dreams of computer enthusiasts are seldom being fulfilled in reality at present, at least in part because of a paucity of good software.

The same problems were illustrated even more recently in data collected by Becker in 1983 (Center for Social Organization of Schools, 1983). Becker surveyed about 1,600 elementary and secondary schools in the United States concerning their use of microcomputers and discovered the following:

--Although most of the academic attention, software development, and advertisement concerning use of microcomputers in schools has focused on improvement of achievement in basic skills by elementary school students, it is the secondary schools that are the largest precollege users of microcomputers.

--The most popular use of microcomputers is to teach students about computers and how to program them using the language BASIC.

--Drill and practice is the most popular use in the elementary schools.

--Of the schools that do teach a programming language, 98% teach BASIC, and fewer than 10% teach Fortran, LOGO, or Pascal.

--In general, the more experience schools have with microcomputers, the more they use them for instruction in programming and the less they use them for drill and practice. This pattern holds for both elementary and secondary schools.

--The majority of teachers view computers as a resource to teach students more about computers but not as a tool to help them teach basic skills. Many teachers who originally thought of the computer as a tool now view it merely as a resource, and very few who initially viewed it merely as a resource have come to consider it to be primarily a tool. (This may change as teachers become more aware of the computer's uses as an instructional tool and as more software intended for use by the teacher--not the student--becomes available.)

--In most schools, only one or two teachers are regular users of computers (typically, the teachers teaching computer programming courses).

--Teachers say that the greatest impact of microcomputers has been social rather than academic. They do not see important effects on achievement, but believe that experience with computers increases students' enthusiasm for schooling and increases their abilities to work independently from the teacher and cooperatively with one another.

--Teachers report that the highest achieving students get the most benefits from the computers, and the low achieving students get the least benefits. This is largely because schools generally use microcomputers for teaching programming to the high-achieving students and for providing remedial drill and practice for the low-achieving students.

--Boys show much more interest in computers than girls and spend much more time using them.

These data are based on a large and representative sample of American schools and thus are likely to be valid. Furthermore, similar findings have been reported by Lesgold (1983) in the United States and by Fletcher (1983) in England, and these findings match our own impressions gleaned from talking to American school personnel and computer manufacturers. School personnel say that computers have proven to be very useful for record keeping (attendance data, report cards, students' class schedules, etc.), but have not proven very useful in the classroom. Few teachers are fearful or hostile toward computers. Instead, they are highly critical of the quality of most of the available software and discouraged by the practical (classroom organization and management) problems associated with classroom use of such computers even when good software is available. Many of the teachers we talked to are even less enthusiastic about computers than the teachers surveyed by Becker, because they report that enhanced student motivation is primarily a novelty effect rather than something inherent in working with computers. Once the novelty wears off, learning with computers becomes just another way to learn for most students.

Amarel (1983) reports similar responses from the teachers she talked to. Here again, the very teachers who were most enthusiastic about microcomputers initially and made the most use of them in their classes eventually pulled back the farthest and remained the most critical. They thought the drill and practice provided by most of the available software inferior to that provided

by traditional materials, and they saw even the good software as not being worth the time and trouble it required for use in the normal classroom situation (partly because such software usually could not be integrated into the program of curriculum and instruction they were responsible for implementing).

In summary, many teachers who have tried microcomputers in their classrooms, usually with initial enthusiasm, have been discouraged by practical problems of implementation and low-quality software. Consequently, unless they are teaching computer programming courses, they usually stop using computers altogether or use them only in ancillary roles (to provide remedial drill and practice for a few low achievers or to provide games as reward or enrichment for students who have completed their regular assignments). Computer manufacturers are well aware of these trends and are adjusting their planning accordingly. Most of the large companies that originally believed schools would want to equip every student (or perhaps each pair of students) with a computer have abandoned that notion and have switched to the home rather than the school as the primary target for design and sales of personal computers. Many of these companies have cut back or eliminated production units assigned to develop software for educational applications. In general, most computer suppliers have abandoned the notion of a computer revolution in schooling, although they do expect that one or two computers per classroom will become the norm eventually. How these computers will be used remains unclear.

There is, then, a tremendous gulf between the visions of computer enthusiasts and the realities of contemporary microcomputer use in classrooms. We believe the situation will improve, especially as better software becomes available and the genuine benefits that computers have are realized. However,

part of the problem is that the educational applications of computers have been oversold, creating unrealistic expectations that, in our opinion, can never be fulfilled.

Unrealistic Expectations

Computer enthusiasts have made several unjustified claims about the presumed capabilities and benefits of computerizing instruction.

First, it is commonly claimed that working with computers is exciting and inherently enjoyable. But once the novelty wears off, learning by computer becomes just another method, akin to learning with the aid of television, filmstrips, listening centers with headsets, and so on. A few students can be expected to retain high enthusiasm indefinitely, but most will not. Many will find working on the computer to be physically confining, slow (one must type in responses, work through programs in preestablished ways, etc.), and aesthetically unrewarding.

Another frequent claim is that the computer will save time and trouble and, in general, remove drudgery from teaching. This may be true for teachers attempting to implement complex systems of individualized instruction that require a great deal of testing and record keeping. For most teachers, however, traditional grade books are far more convenient than computerized record keeping, and traditional instructional methods and materials are more convenient than computerized approaches. To the extent that teachers begin to incorporate computers into their instruction, it will be because computers offer benefits that are worth the extra trouble, not because they simplify the process.

Computerized instruction will not save time and trouble or remove drudgery for students. With a few exceptions to be discussed, computerizing

instruction does not involve basic changes in the nature of instruction; it merely changes the form in which the instruction is delivered (by computer rather than by the teacher, a textbook, a workbook, or a ditto sheet). Even for drill and practice applications, comparisons between the computer and other forms of instruction are not necessarily favorable to the computer. Books are easier to read, more portable, and otherwise more flexible in their usage than material stored in a computer that must be accessed through a video monitor. Most two dimensional illustrations that can be shown on a screen can be shown as well or better in a book, and most three dimensional or time sequenced illustrations can be shown as well or better on film or videotape than through computerized approaches.

It is often claimed that computerized instruction is uniquely capable of developing creativity, problem-solving skills, and other higher level cognitive abilities. Again, most of what can be done in these areas by computer is essentially no different than what can be done using more traditional methods and materials. Furthermore, it should be kept in mind that providing students with opportunities to practice or apply high-level cognitive skills is not the same as helping the students to acquire or develop such skills in the first place. Computer enthusiasts, especially those involved in developing complex simulation exercises, often imply that participation in such simulation exercises will teach higher-level concepts and skills. But such higher level concepts and skills must already be present if the learner is to understand and profit appropriately from the simulation exercise. As Arons (1984) puts it,

> If the computer is used in such a way as to involve the student, and if it facilitates the making of measurements not obtainable by simpler and more transparent techniques, it can be beneficial. However, if it short-circuits insight, if it simply makes available end results for analysis or confirmation, it is educationally sterile or even deleterious. (p. 1051)

Enthusiasts often picture the programming of computers as a mind-expanding, creative activity. But once the novelty wears off, most people find it boring, repetitious, and unrewarding. Learning to program is much akin to learning a second language. It does not so much involve creative thinking (generation of thoughts) as it involves translation of thoughts into a form and language understandable to the computer. Even LOGO and other applications involving geometric forms in addition to language are better thought of as disciplines or restricted mediums within which to translate and express ideas than as methods of stimulating idea generation. In effect, LOGO is a computerized version of activities such as mechanical drawing or working with a compass and protractor, although it has the advantage of allowing for simple error correction and revision. In any case, Thorndike showed long ago that specific mental disciplines and cognitive activities do not have generalized mind building effects; thus there is no more reason to expect generalized intellectual benefits from learning to program than there is to expect such benefits from learning Latin or Greek.

Underappreciated Problems and Limitations

Besides propounding unrealistic claims and expectations about what computers can do, many computer enthusiasts have so far ignored or failed to come to grips with certain serious practical problems and limitations on their use in the classroom.

One is cost. Although it is true that improvements in technology have led to geometric increases in the computing power purchasable for a fixed cost (about $1,000 per unit), it is also true that this cost has gone down about as far as it is going to go. Unlike hand-held calculators, powerful microcomputers are never going to become extremely cheap. Industry estimates project that the $1,000 per unit price will remain as the norm indefinitely.

Low-power computers suitable for playing certain kinds of games or supplying typing and minimal text editing capacities are becoming considerably cheaper, of course, and we can expect to see more of these appear in classrooms (perhaps one or two per class). However, powerful computers capable of handling the more complex tutoring and simulation programs (i.e., the ones most likely to provide unique functions that cannot be supplied through traditional methods and materials) will remain expensive. Cost factors are likely to keep computer purchases closer to a norm of one computer per classroom, rather than one computer per student. Even computer programming classes are likely to have to make do with one computer for every three or four students. Also, note that the $1,000 per unit figure does not take into account software costs, and good software packages are expensive and likely to remain so because they are necessarily labor intensive to produce.

There are also costs in time, trouble, and inconvenience. Books and related classroom materials can be supplied in volume and are usually hardy enough to stand up to the pounding they get from students. In contrast, floppy disks can be used by only one student or a small group at a time, are difficult to store and retrieve conveniently, and are easily ruined if dirtied, torn, or stepped on. These problems should be reduced as manufacturers begin to supply hardier disks and as schools begin to "network" their computers (so that a single disk can be accessed through each of the microcomputers in the network, without requiring the students to handle the disks themselves). For now, however, these problems are of serious concern to teachers.

Computer enthusiasts often have unrealistic expectations about teachers' time and interest in using computers. Some even assume that teachers will want to do their own programming and have developed approaches that require teachers to do so. But few teachers have the time, skills, or inclination to

do their own programming; they are likely to use computerized approaches only if such approaches are convenient (i.e., no more trouble than a filmstrip machine or video cassette recorder). Anything that requires programming or even typing more than a word or two is unlikely to be used, as is anything that requires the teacher to stay with and continuously monitor the work of a single student or small group interacting with a computer.

This should not be interpreted as evidence that teachers are impossibly conservative and wedded to traditional activities, or that the problem is temporary due to fear of or unfamiliarity with computers. Teachers have limited time outside of class and have classroom management and instruction duties that keep them almost continuously occupied during class. Any instructional approach (computerized or not) that fails to accommodate to these realities will not be used in the typical classroom.

Computer enthusiasts also frequently have unrealistic expectations about students. First, computerized learning is not automatically easy or enjoyable. It places more restrictions and makes more demands on the student than do video games or other "fun" activities associated with computers. Furthermore, although game formats are often used, the material still involves teaching and learning rather than "games" in the usual sense of that term. Once the novelty wears off, learning by computer is just another way to learn.

Also, it is often a demanding way to learn. At minimum, computerized instruction requires typing and other computer-use skills. Usually, it also requires the ability to read and follow directions and, in general, to work independently over significant time periods. By the secondary grades, it may also require well developed formal or abstract thinking and learning skills.

It can be frustratingly slow, especially when students can supply the answers to questions instantaneously and with certainty of their correctness,

and yet must take the time to type them in and get verification from the computer before being able to move on to the next step.

In summary, computer applications to schooling have been oversold by computer enthusiasts. Computers cannot deliver on some of the unrealistic claims made in their behalf, and computerized instruction involves not only financial costs, but costs in time, trouble, and inconvenience to both teachers and students. Are there computer applications in the classroom that could provide benefits worth such costs? In the remainder of this paper, we respond to this question.

Potential Role of Microcomputers in Classroom Instruction

Before discussing present applications and speculating about possible future applications of microcomputers to classroom instruction, we need to mention some limits on our discussion and some of our assumptions. One limit to bear in mind is that our focus is on computer applications to classroom instruction and not on broader applications to research and development or the conduct of business and industry. We grant that computers have truly revolutionized the state of the art in many areas of human endeaver; we doubt, however, that they will have very basic or powerful effects on schooling.

Our discussion will also be focused on K-12 classrooms in which typical teachers work with typical classes under typical conditions. We do not address issues in personnel training in industry or the military, and we have little to say about instruction in K-12 special education settings or post-secondary institutions.

Basic Assumptions

Schooling, as it has evolved through the centuries (age-graded classes in which one teacher works with 25-35 students), is a compromise solution to the

problem of providing each individual student with the materials and instruction best suited to his/her specific needs (accomplished most effectively through expensive individual tutoring) at minimal cost. The whole class (supplemented by a degree of small-group and individualized) instructional methods that have evolved over time work reasonably well for most students, although some students do not get enough individualized attention from the teacher and a degree of regimentation and behavior control is necessary in order to make the system work. Because the economic factors that dictate a student-teacher ratio of about 30 to 1 seem unlikely to change, we assume that only those proposed schooling innovations compatible with this ratio and the constraints on teacher and student behavior dictated by it will be adopted widely.

One such constraint is that teachers must monitor and be prepared to respond to events occurring anywhere in their classrooms at any time if they are to keep the students continually engaged in academic activities. Proposed innovations that demand sustained teacher attention or action (such as requiring teachers to program or type statements into a microcomputer during class time) or that require teachers to stay in one place or deal with one student for more than a few minutes at a time (such as when continuously monitoring and responding to a student's interactions with a computer) will be impractical for use in normal classrooms because they will prevent the teacher from monitoring and assisting the rest of the class.

We also assume that students, especially in the early grades, require active instruction from their teachers. One of the more consistent findings from process-product research conducted in U.S. schools in the last 15 years is that student achievement is higher when teachers instruct their students actively--carry the content to them personally by providing explanations and

demonstrations and conducting recitation lessons--than when teachers expect students to learn primarily on their own through interacting with textbooks and individualized instructional materials (Brophy, 1979; Brophy & Good, in press). Young students in the early grades do not have the functional reading, direction-following, and learning-to-learn skills needed to learn effectively on their own and thus are particularly dependent on active instruction by the teacher. Furthermore, even students who have the academic skills needed to learn individually often have difficulty doing so because of motivational problems, learning style preferences, or limitations on attention span and concentration. Finally, even bright, well motivated secondary students who seem to be progressing smoothly through independent learning units tend to run into trouble before long if not monitored closely by their teachers, because they usually harbor erroneous misconceptions about the content that sustain themselves indefinitely unless discovered and challenged directly (Eaton, Anderson, & Smith, 1984), and because they develop "buggy algorithms" that allow them to get correct answers on the present assignment but are fundamentally incorrect, causing trouble later on other assignments (Erlwanger, 1975; Davis, 1984).

A related assumption is that active instruction by the teacher is most essential during the acquisition phases of learning when basic concepts or skills are being developed, compared to the practice or application phases when these basic concepts or skills are being applied. Thus, as a general rule, we expect individualized learning approaches (including computerized approaches) to have their most useful applications as methods for providing drill, practice, or application experiences to students following initial instruction by the teacher, rather than as vehicles for providing such initial instruction in the first place. This means, in effect, that we expect

teachers to retain their traditional places as the primary instructors in the classroom, with individualized learning programs (including computerized ones) playing an important but nevertheless ancillary role. Most computer enthusiasts realize this, but some think of the computer as becoming the primary instructor in the classroom, with the teacher playing a more ancillary role as an instructional manager concerned primarily with seeing that students are provided with the programs they need (relying on computerized record keeping to help keep track of all this), and only secondarily providing instruction to the students (typically to individuals, primarily in the form of clarification concerning confusion that arises as they work through programs individually). Despite the many strengths that computerization brings to individualized instruction, the latter scenario is highly unrealistic, and no more likely to succeed than the ill-fated "teacher-proof curricula" that were tried and found wanting in U.S. schools in the 1960s and 1970s.

Thus for the remainder of this paper we assume that the teacher will remain the primary instructor in the classroom, with computerized approaches taking on ancillary functions. We also assume that much better software will become available than is generally available now, software with pedagogically valuable curriculum and instructional content designed for use in typical classrooms (programs designed for teachers to use with the whole class or for students to use with partners or groups of peers, in addition to programs for students to use individually).

This is a major and questionable assumption, because there is no guarantee that such ideal software will be developed in the near future or that it can be developed cheaply enough to make it feasible for widespread adoption in schools. However, it is necessary to make this assumption in order to consider the ways that computers might begin to make significant,

qualitative differences in the effectiveness of schooling. If we restrict the discussion to what is available now (and especially to what can be ordered immediately at reasonable cost), there would be very little to say except that in general, computers have not fulfilled their promise and are not being used much in classrooms except for courses in computer applications.

Within the constraints described above, we believe that incorporation of microcomputer technology into classroom instruction can enhance that instruction, mostly by enhancing the effectiveness of existing techniques but occasionally by introducing entirely new capabilities. Taylor (1980) has noted that computers can serve educational functions in the classroom in three ways: as a *tutor* that instructs the students and monitors their practice, as a *tool* used by the teacher to augment the scope or effectiveness of instruction, and as a *tutee* that the students can "teach" through programming. We have used this scheme to organize our comments about potential computer applications to classroom instruction:

--tutoring functions, which include drill and practice, tutoring, simulation, and instructional games;

--tool functions, which include word processing, demonstrations (including spreadsheeting, graphics, and computer-aided design) and computer managed instruction; and

--tutee functions, which include programming and editing.

Tutoring Functions

Drill and practice. Drill and practice are often scorned or looked upon as drudgery, but they are extremely important components of a well rounded instructional program. If students are to assimilate and apply basic concepts and skills, they must first master them thoroughly, to the point of being able to make smooth, rapid, correct responses when required to do so. This is

especially the case with basic "tool skills" and with concepts and skills that occur early in a hierarchically organized sequence of curriculum and instruction.

Computerized drill and practice could be useful, especially to the extent that they go beyond drill-and-grill or electronic-page-turning programs. Given equal pedagogical value of the content of the instruction, computerized drill and practice programs compare well with traditional workbooks, and even with programmed instructional materials, if they include certain features that take advantage of the computer's capabilities. First, the computerized approaches require the learner to consistently make active, overt responses to questions and commands and supply the learner with immediate (but private and largely encouraging) feedback. This increases the chances that the learner will pay close attention to the task and try to master the material, and it probably reduces the frequency of cheating and undesirable guesswork. Second, programs can be presented in game formats, which, if done properly, can enhance their motivational value without damaging their instructional effectiveness. Third, if the computer's capabilities for storing information and branching the learner's progress through appropriate subprograms are exploited properly, computerized programs can not only provide drill and practice in the form of questions and feedback, but also systematically record the learner's responses, diagnose error patterns, and provide needed reteaching and recycling through instructional strands that require extra work.

Programs with these capabilities could be invaluable, especially for providing individualized remediation and extra instruction for weaker students. Such programs clearly can be developed (see next section), although they are expensive to produce because they require sustained, painstaking efforts by experts in the particular area of curriculum and instruction involved

(algebra, physics, etc.), and because they require powerful computers (except for brief booklet-sized programs that can be completed in an hour or two). It remains to be seen whether software sophisticated enough to include these diagnostic and prescriptive functions can be produced cheaply enough to allow widespread adoption in the schools.

For now, drill and practice programs are most effective in two situations: (1) drilling students on facts that must be committed to memory largely through rote learning processes, because they cannot be learned as specific applications of more general principles (this applies mostly to factual knowledge taught in the early grades); (2) drilling students on responses that follow general principles (at least to some extent) but nevertheless must be mastered to the degree that the responses can be produced smoothly and instantaneously whenever needed (e.g., foreign languages and basic mathematical factors and algorithms).

Tutoring. Computerized tutoring programs are designed to teach concepts by presenting information and then asking questions, getting student responses, and providing feedback and subsequent instruction. Such programs can be effective with students who have sufficiently developed reading and learning-to-learn skills, although not as effective as active instruction from the teacher in most cases. Tutoring programs are likely to be most effective where errors are predictable and diagnostic of student misconceptions or learning needs and least effective when students are likely to make wild guesses or to produce an extremely diverse set of responses to the questions asked.

Such programs will be very expensive to produce, not only because high level and specialized expertise is needed to inventory students' error patterns and develop effective prescriptive instruction matched to their

needs, but because the sheer number of possible error patterns is discouragingly high. Brown's research on "buggy algorithms" (Brown & Burton, 1978), for example, has uncovered over 100 common error patterns in algebra (which would appear to be a well-circumscribed subject likely to engender relatively *few* such error patterns, compared to, say, science or social studies). Still, such diagnostic and prescriptive tutoring is possible in theory, and prototypes such as Brown's BUGGY program and the "router" used in the PLATO program are already in existence.

Work is also in process on programs that use a Socratic dialog approach to tutoring, in which series of questions are used to lead the student through lines of reasoning to insights and conclusions. Such programs appear to be especially promising as vehicles for helping students to develop operative knowledge (knowledge of how things happen, for example, as opposed to knowledge of simply that they do happen). Arons (1984) also notes their potential for developing hypothetico-deductive thinking skills in students and helping students to recognize gaps in available information, move back and forth between symbols and words, and "find the problem" in complex mathematical applications. To the extent that such tutoring programs can be made practical (in terms of cost and integration with the typical school curriculum), they probably would become valued components of classroom instruction.

Simulation. This is one of the areas where microcomputers make possible activities that could not be done with other methods. Computerized simulation exercises can provide practice in decision making and problem solving in ways that are more efficient and likely to be experienced as more "real" than other simulation approaches. They can provide for immediate feedback concerning the outcomes of one's decisions or actions, and the spreadsheet functions of computers can allow for elimination of repetitive calculations and other time

consuming steps that might be involved in proceeding from a decision or action to determination of its effects. If learners understand the nature of the steps that are being skipped over because the computer is handling them, this approach will allow them to gain expertise rapidly by working through many more practical problems than would be possible in the same time frame using different methods. If learners do not understand what the computer does with their decisions and action choices, however, the whole exercise becomes a black-box guessing game of dubious value rather than an effective teaching method.

Computerization can be introduced with any kind of simulation activity, but it will make the most difference with simulations that involve lengthy step-by-step processes of building and testing the assumptions of models of reality. At present, elaborate simulation programs are in use in training various practitioners (e.g., physicians, special education teachers, reading specialists) to perform reliable and accurate diagnoses. There are also many present and potential applications in classes that involve considerable decision making and problem solving (e.g., engineering, architecture, mechanical and electrical trouble shooting, economics, political science). Any situation that requires a person to use probabilistic data in order to make judgments or decisions under conditions of uncertainty will be amenable to computerized simulation. Starting in the upper elementary grades and increasing throughout the secondary grades, there should be many opportunities to incorporate such simulations into applied exercises in science and social studies.

The graphics capabilities of computers have potential uses far beyond those seen in computer games or elementary LOGO programs. In particular, computer graphics have many applications in art and handicraft courses where computer-aided design capabilities can facilitate product design. In

mathematics courses, computers offer an advantage over calculators in that they can express results graphically as well as numerically, thus providing a visual dimension to work with variables expressed numerically.

In mathematics classes, the spreadsheeting and number-crunching functions of computers should save time and allow more applied work in topics involving recursions, derivations, or extrapolations. These same functions can be drawn upon for mathematics-based applications in other classes, such as the testing of models developed to explain scientific phenomena, the forecasting of non-obvious effects of changes in existing social or economic conditions, or the development of specificiations for construction projects in shop courses. These applications of computers have yet to become widely used, even in mathematics classes (Fletcher, 1983), but the potential is clearly there.

If these applications should become well established, they may begin to affect the mathematics curriculum itself. The widespread use of calculators, for example, has led to calls for reduction in time spent on multiplication and division of large numbers (which are now done by calculator instead of by hand), but more emphasis on estimation and answer checking skills (because students need to be able to evaluate whether or not the answers they get from calculators are probably correct). If computers have a similar impact on mathematics instruction, we may begin to see less emphasis on calculus and more on such topics as combinations, graph theory, and coding theory.

Instructional games. Games such as "Pacman" have no educational value and will distract students from their studies if introduced into the classroom. However, programs that teach or allow application of academic concepts and skills in a game format and provide enjoyable as well as instructive alternatives to traditional seatwork, and games that present intellectual challenges or require complex strategy development in order to solve problems,

do appear to have educational value. Such games will always be ancillary--used for remediation or enrichment rather than as the basic mode of instruction--but they are likely to become commonplace in classrooms because students enjoy them, they can be purchased cheaply, and they are easy to use with little or no teacher supervision.

Tool Functions

Word processing. Just as in business settings and in the home, the word processing capability of microcomputers is one of its most useful capabilities in the classroom. There are at least three important ways that the microcomputer, when hooked up to a printer, can enhance classroom instruction in reading, writing, and language arts.

The first is simply through exposing students to typing and related computer-use skills. Following trends in the business world, schools are beginning to use microcomputers rather than traditional typewriters for typing instruction because most typing done later in occupational settings is likely to be done on microcomputers rather than typewriters. Even in the early grades, students enjoy typing material into the computer and getting printouts that have a professional appearance (Levin & Boruta, 1983). Furthermore, programs are becoming available that teach typing skills in game formats, thus making the learning more enjoyable.

The second, and most common, application of the word-processing capabilities of microcomputers is in composition instruction. This capability allows students to correct mistakes in their compositions and yet yield a final product that is clean and attractive rather than filled with eraser smudges or crossed out words, and it allows them to make insertions or other revisions in compositions without having to recopy the entire composition from scratch. If

equipped with appropriate programs, microcomputers can also assist students in identifying spelling errors and arranging their compositions in good form. If a printer is available, the students can take printed copies of their compositions with them to work on in between sessions on the computer, so that one microcomputer can serve many students efficiently for these purposes. A final noteworthy feature is that the completed product (as well as various intermediate versions) will be easier for the teacher to read and correct than students' handwritten copies would be, thus making it easier for the teacher to include more composition instruction in the curriculum, something that is recognized as very important but which nevertheless is often slighted because it takes up so much teacher and student time.

Programs are becoming available for teaching students to plan and write stories or poetry, or to guide students in planning and editing their stories by responding to questions (Lawlor, 1982). So far, results of field tests of these programs are mixed, and it remains questionable whether students who learn to construct stories or poems by following the guidance of a computer program will learn any more or better than students taught with traditional methods. Nevertheless, these approaches remain promising and would be relatively cheap and easy to implement in the classroom if they prove their pedagogical value.

A third useful application of microcomputers is in facilitating the language experience approach to early reading and writing. In this approach, children are taught to read and write the language they already use orally. The textual material used for this instruction is dictated by the children themselves and copied by the teacher. Obviously, there are motivational and pedagogical advantages to beginning reading and writing instruction by using words that are already both familiar and interesting or important to the

student. However, proper implementation of the approach requires eliciting and copying material dictated by each individual student separately, and this takes a great deal of time.

Recently, however, methods have been developed to facilitate this process through microcomputers, which allow the teacher (and later the children themselves, as they acquire typing skills and familiarity with sentence composition and spelling) to type and produce printed copies of children's dictated composition (Avinger, 1984).

A drawback of this and related applications, of course, is that they still take considerable teacher time spent typing material into the computer. This problem could be solved at some point in the future if and when voice activation of computers becomes perfected to the point that students could orally dictate their compositions directly into the computer, which would then type the material and create a printed copy. Such applications are clearly possible in principle, although it remains to be seen whether they can be made sufficiently user friendly to be applicable to young children in classrooms. When perfected, these programs may still require very precise word pronunciation or have other restrictions on language usage that would make them inappropriate for use by young children whose language capabilities are still developing. It may be difficult to prepare programs good enough for practical use in classrooms at a reasonable cost. Also, development of practical voice activation may prove to be more difficult in English than in most other languages. In any case, even if such development fails to occur, the word processing capabilities of microcomputers are among the most important capabilities for classroom usage, particularly in courses dealing with reading, writing, and language arts.

Demonstrations. Computers have color, sound, and graphics capabilities that make it possible to use them for a variety of demonstrations. For the most part, such capabilities parallel those offered by alternative methods such as overhead projecters, filmstrips, films, or videotapes. Ultimately, however, if classrooms become routinely equipped with microcomputers and associated videodisc technology, to the point that demonstrations intended for classroom use are manufactured for presentation via microcomputer and video monitor, the need for most other forms of equipment (particularly filmstrips and videotapes) would be eliminated.

In any case, the three dimensional realism, color capabilities, and other features of videodisc technology make it very useful for presenting powerful demonstrations, especially when it is important to show the sequential movement of three dimensional objects through space and time. In addition, computers present unique capabilities for interactive demonstrations when used for some of the purposes described above in the section on simulation. In mathematics, for example, these "interactive electronic blackboard" capabilities of computers can be used to demonstrate recursions, derivations, or extrapolations without consuming much time. The instructor not only can show students a prepared demonstration of some phenomenon, but also can demonstrate what will happen if the values of variables are changed. Thus, the unique contribution of microcomputers is not so much in the quality of initial demonstrations, but in their capacity to simulate activities following these demonstrations.

Computer managed instruction. Several systems of individualized instruction are available in which students take diagnostic tests that determine where they should begin in the program and then work at their own pace through prepared sequences of curriculum objectives. These programs keep the teacher

very busy administering criterion tests and seeing that students move on to the next appropriate curriculum sequence, in addition to providing help to students who need it. Computer management can save much of this time by recording and summarizing the scores from tests that the students take on the computer and by keeping track of which curriculum units each student has completed and how s/he performed on them. Such computer management can be very helpful to teachers working with individualized programs, although as noted previously, such programs are not advisable for typical classroom situations.

Tutee Functions

In the tutee functions of programming and editing, students program the computers themselves to solve problems, develop graphics, write programs for themselves or others to use, or refine existing programs. Such applications are most relevant, of course, to courses on computer use and programming, although certain students may want to learn to program computers for a great variety of reasons. Such programming experience probably will be of some educational value to the students, although this value should not be overemphasized.

The value of learning to program computers is often overemphasized, in at least two ways. The first has already been mentioned: learning to program a computer will probably have as much cognitive stimulation value to a student as learning Latin or Greek, but no more. Programming requires students to think clearly about operational procedures, but it does not stimulate intellectual development directly or teach them how to think or generate complex or abstract ideas.

The presumed practical applications of programming instruction have also been overemphasized. Despite the dramatic effects of "the computer revolution" on certain sectors of business and industry, there is no reason to

believe that the typical person will need to know how to program computers any more than the average citizen today needs to know how to construct or repair electrical appliances. It is probably true that every citizen should have some familiarity with computers, and most should learn the typing and related skills used in operating computers. It may even be a good idea to teach at least rudimentary programming to most students in order to develop their understanding of how computers work. Still, it is unlikely that many citizens (other than those in the computer industry and related fields) will ever need to program a computer themselves. Most users of computers in the business world and even in the home will be using them only for routine functions controlled by software developed for those purposes and designed to be user friendly to the point that no programming and little difficulty of any kind are involved. There are some valid arguments for teaching students to program computers and giving them opportunities to do so, but these arguments do not include either the notion that such programming experience will be needed for everyday life in modern society or the notion that such programming experience will stimulate intellectual development generally.

Conclusion

Many of the claims concerning computer applications in the classroom are unjustified or overblown, and most of the apparently realistic potential applications remain dreams rather than realities for now because of inadequate or inappropriate software development, unacceptable costs in time and trouble as well as money, or other practical problems. It seems clear that microcomputers will never replace teachers as the primary instructors in the classroom, but that they do bring capabilities (particularly in word processing and simulation) that could enhance instruction by allowing teachers to do things that are difficult or impossible to do now.

To evaluate potential classroom applications, one cannot make global judgments about the value of computers considered generically. Instead, one must consider the specific functions that computers can be programmed to fulfill within particular classrooms, and weigh the costs and benefits of the computerized approach against those of alternative approaches. Computerization offers worthwhile advantages only in certain contexts and for certain functions--largely the same ones for which it offers advantages in the home and the workplace. The most promising possibilities for using computers as teaching tools are in applications involving "the three R's"; recursions (rapid algorithmic processing, number crunching), revision (text editing, spreadsheeting, product design), and rapid hypothesis testing (simulations, problem solving). Few of these potential classroom applications are being realized at present, but more of them should begin to appear commonly as software develops, especially software intended for use by teachers working with the class rather than by students working individually.

In the meantime, however, school administrators and policy makers are well advised to move slowly in considering microcomputer purchase and use in the classroom. Rather than just purchasing microcomputers and turning them over to teachers to figure out how to use, school administrators should spend considerable time informing themselves about available resources and capabilities; considering the compatibility of various software with the hardware manufactured by various suppliers (until standardization evolves or becomes enforced by consumer demand or government edict, schools are continually going to be frustrated to discover that desirable software cannot be used with the hardware they have purchased); getting information from teachers or arranging small-scale tryouts of software before implementing programs on a large scale (relevant data on software come from teachers who have used the programs, not

from manufacturers' representatives); involving potential users of the software in decisions about what to purchase; budgeting for software purchase, maintenance, and training (in addition to hardware purchase); and other practical matters. Tucker (1983) provides useful advice on how school districts can prepare systematically to make intelligent decisions about microcomputer purchase and use in their schools, and Lathrop (1982) provides guidelines (and a useful bibliography) for evaluating the quality of software.

In conclusion, although microcomputers cannot deliver the benefits claimed by computer enthusiasts, they do have the potential to significantly enhance the quality of instruction in schools, especially if better software is developed and delivered at affordable prices. School systems that keep their expectations realistic, inform themselves about what is available and how it is being used in classrooms, and demand data on the outcomes of field trials of new programs are likely to make good purchase and use decisions and to derive limited but significant benefits from introducing microcomputers to the classroom.

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